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# THESIS

DEVELOPMENT OF NATOPS  
PERFORMANCE SOFTWARE  
FOR THE H-46D HELICOPTER

by

John Michael Caram

March 1985

Thesis Advisor:

D. M. Layton

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Development of NATOPS Performance Software  
for the H-46D Helicopter

by

John M. Caram  
Lieutenant, United States Navy  
B.S., University of Florida, 1977

Submitted in partial fulfillment of the  
requirements for the degree of

MASTER OF SCIENCE IN AERONAUTICAL ENGINEERING

from the

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## ABSTRACT

This thesis generates closed-form equations for significant and frequently used NATOPS performance charts for the H-46D and H-46A (with T58-GE-10 engines) helicopters. These equations are developed into interactive software for the Hewlett-Packard HP-41CV hand-held programmable calculator. With this software installed in the calculator the user is able to calculate numerous NATOPS performance parameters (expeditiously, with reduced risk of error) both prior to and in flight.

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## I. INTRODUCTION

### A. COORDINATION OF EFFORT

A similar software development for the H-3D and H-3H helicopters was conducted at the same time as this development by Curtis [Ref. 1]. Because of the nature and complexity of the problem, the initial stages of these investigations were a joint effort. As a result, the Approach to the Problem (Chapter II) and the basic method of the Solution (Chapter III) of this work and of Reference 1 are very similar.

### B. BACKGROUND

Performance planning is an essential task to ensure the safe conduct of any aircraft and crew during their flight. Naval aircrew use the Naval Air Training and Operating Procedure Standardization (NATOPS) manual to acquire all necessary performance data. For the most part, NATOPS performance information is presented in a graphical format often requiring the user to transit several subcharts, which may be located on different pages, to obtain the desired performance parameter. This procedure is time consuming, prone to error, and impractical in-flight.

The purpose of this thesis is to propose a correction to these NATOPS deficiencies by transforming selected performance charts into interactive, user-friendly, computer software for a hand-held programmable calculator. This solution would enable aircrew to obtain performance data with increased accuracy, reduced time and effort, and permit in-flight use.

Previously there have been several successful efforts in NATOPS computerization. The most recent study [Ref. 2] developed software for the A-6 aircraft utilizing the Hewlett-Packard HP-41CV hand-held programmable calculator. This research demonstrated the feasibility of NATOPS computerization and was a prime motivator for this thesis.

### C. GOALS

The first goal of this study was to generate a closed-form equation for each selected NATOPS chart or subchart. The equations were required to be of a form such that independent variables were the specific chart input parameters and the dependent variable, the output parameter. The equations used to "fit" each NATOPS chart had to allow an explicit calculation of the dependent variable. Furthermore, they had to consist of standard functions (no differentials/integral equations) which could be programmed on a calculator or computer.

Once the equations representing the performance charts had been derived, it was necessary to select the hardware which would be used for software design. The HP-41CV programmable calculator was selected due to its small size, relatively large memory capability (6.4 Kbytes), and successful use in the past.

Upon completion of the software development the ultimate goal of this research was the testing and implementation of the end product into the fleet.

## II. APPROACH TO THE PROBLEM

The first and foremost problem encountered was the generation of the closed-form equation in a manner which accurately represented each performance chart with a minimum number of terms. For the majority of charts considered there were two independent input variables that yielded a single dependent output variable. This was visualized as a three dimensional surface in space.

To accomplish fitting an equation to a surface of irregular nature required the utilization of a numerical regression routine. These routines are numerous and have been developed into several software packages for main frame computers. The software chosen for this study was the Biomedical Computer Program (BMDP) statistical package [Ref. 3], installed on an IBM 3033 main frame computer located at the Naval Postgraduate School in Monterey, California. A regression is linear in nature no matter how many independent variables are involved. However, nonlinear functions may be used in a regression if they are first "linearized". For example, if the nonlinear functions  $x^2$ ,  $x^3$ , and  $\ln(x)$  are transformed into independent variables (transforms)  $U$ ,  $Y$ , and  $Z$ , respectively, then a regression can be performed to yield an equation of the form:

$$S = aU + bY + cZ + d \quad (\text{eqn 2.1})$$

where  $a$ ,  $b$ , and  $c$ , are the regression coefficients,  $d$  is the intercept, and  $S$  is the dependent variable. The specific BMDP routine used for the majority of charts analyzed was the "all possible subset" multiple regression routine (P9R) which allows the user to input a large selection of

transformed independent variables to be examined during the regression analysis. The P9R could be selected to either use all transformed variables offered (method is none), or perform the regression selecting subsets of the offered transforms and output the subset with the best fit statistics (method is CP).

The dominating criteria used to determine the best fit statistics was the squared multiple regression correlation ( $R^2$ ). Accuracy was gauged by how close  $R^2$  was to the ideal value of 1.0. The required  $R^2$  for an acceptable fit was found to vary between performance charts, and was a function of what dependent output variable was being generated, the irregularity of the surface, and the number of independent input variables. For each chart multiple regression analyses were performed varying the offered transforms in number and/or type, until a closed form equation was generated that yielded output that was within the accuracy of manual chart interpolation.

The accuracy with which NATOPS chart could be read was subject to the individual chart's characteristics, but in general the following tolerances for dependent variables were established (for the regression analysis).

- airspeed: within 2 knots
- altitude: within 100 feet
- weight: within 150 pounds
- torque: within 1 %
- distance: within 1 mile
- time: within .1 hour

Prior to the execution of the regression program, a data file for each surface was created. The file consisted of data sets which were merely the independent variable values and the corresponding dependent variable value. For a three dimensional surface each data set consisted of three values. It was critical to ensure that the data sets extracted from



a performance chart were as accurate as possible and that the data file clearly defined the surface. Obviously, those surfaces that were irregular in nature required significantly more data sets than smoother or more "well behaved" surfaces. If a surface contained a sharp point or discontinuity, this portion of the surface was eliminated from the regression analysis due to the inability of the software to accurately fit aberrations.

The transformed variable selection was the key to successful regression analysis. Through experience one gained an intuitive feel for what type of transformed variables would yield a close fit to a surface. Fortunately, most of the surfaces responded well to regression analysis utilizing combinations of the independent variables raised to powers between one and four (polynomial regression). A standard polynomial regression program was developed containing all the possible polynomial terms up to the fourth order, for three and four dimensional surfaces.

For a few surfaces, obtaining a close fit by regression analysis incurred the penalty of retaining a large number of transformed terms. An alternative to this was to fit each of the depicted influence curves and develop the final computer software to interpolate between curves. The trade off with an interpolation scheme was increased accuracy at the expense of inordinate program size and complexity, causing the result to be unacceptable. In a few cases it became necessary to use nonlinear transforms of the independent variables such as exponentials, and high order fractional combinations of terms (Appendix B: pp. 64-65).

On the first execution of each regression analysis "method is none" was selected in the P9R program. This keyed the BMDP software to use all the offered transforms for the regression analysis. During execution, matrix algebra was performed with the independent variables and

transforms. If this algebra created numbers outside the tolerance range specified in the program (default tolerance = .0001), the "method is none" option would eliminate the offending variable, or transform, and continue execution. The resulting output contained the  $R^2$  value along with other fit statistics and listed all terms eliminated for low tolerance. Performing a second iteration with the out-of-tolerance transforms eliminated, and with "method is CP" selected, allowed the BMDP software to analyze subsets of the remaining transforms. Performing this two step process yielded the best fit with fewest terms for each surface.

### III. THE SOLUTION

The polonomial transform program yielded acceptable regression results in the majority of cases. For the performance charts that had difficult surfaces to fit, requiring as many as 38 transformed terms (Appendix B: p. 58), it was found to be advantageous to take the penalty of a large regression equation rather than fitting influence lines and interpolating between them. Of all the surfaces considered (23), only the single engine envelope (Appendix B: p. 64) required nonlinear transformed terms, specifically exponential and high order fractions.

#### A. EXAMPLE SURFACE REGRESSION ANALYSIS

The engine performance chart Figure 3.1 was chosen to illustrate the regression technique since it demonstrated the capability of numerical regression to generate an accurate closed form equation of a fairly irregular surface.

The first step in the solution of this performance chart was to create the data file for the regression program. Data sets were taken along each pressure altitude influence line at increments of 10° centigrade (C) with additional points added for the 4000 to 6000 foot altitude lines, due to their close proximity to each other. Each of the 155 data sets consisted of two independent variables (temperature and altitude) and the resulting dependent variable (torque). The sea level altitude line was omitted since it could be calculated directly (linear equation) and due to its discontinuities at -5 and 15 °C causing difficulties in fitting the surface.

Next a numerical regression was performed with the "method is none" option selected utilizing the standard fourth order polonomial (22 transforms) discussed earlier. The resulting output listed the terms excluded from the regression analysis due to exceeding tolerance limits (4), the regression  $R^2$  (.99942), and other fit statistics. The high  $R^2$  value indicated that the selected polonomial transforms were representative of the surface.

The next step was to determine if some of the retained transforms could be eliminated without significantly effecting the fit. The four out-of-tolerance terms were deleted from the transform selection and the program was executed with the "method is CP" option in effect. This resulted in an elimination of eight transforms while only degrading the  $R^2$  value to .99936 (Appendix B: p. 36).

The equation for the surface was tested by writing a program stub and checked to ensure accuracy. Since the surface fit did not consider altitudes below the 2000 foot line, an interpolation routine was required in the final program to calculate torque when pressure altitude was between 2000 feet and sea level.

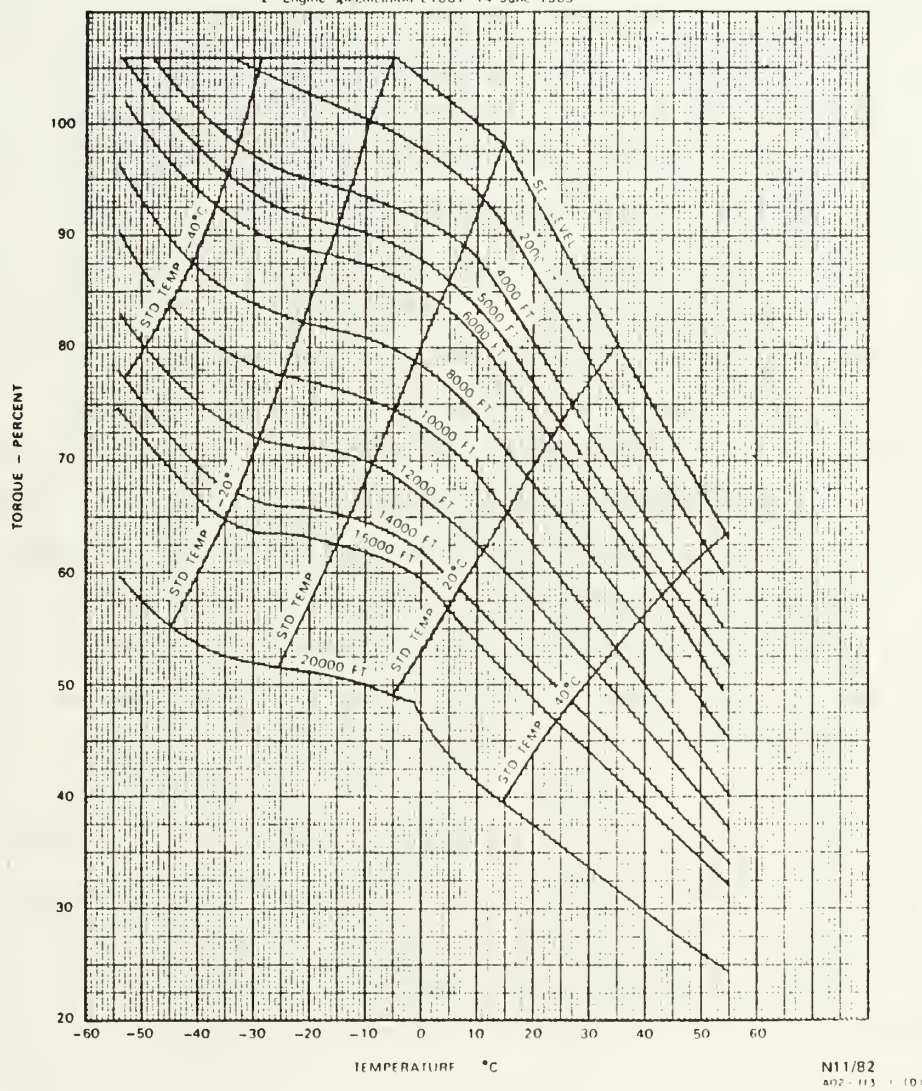


ROTOR RPM 100 PERCENT

FUEL GRADE JP 4, JP 5

NOTES

- 1 Shaft horsepower reduced 92 percent for installation losses  
2 Engine specification E1081 14 June 1963



**Figure 11-1A. Engine Performance (Military Power – 100 Percent  $N_T$ )**

11.5

Figure 3.1 Engine Performance (Military Power - 100% Nr)

#### IV. RESULTS

At the onset of this study 10 different NATOPS performance charts were selected for computerization based on their significance and frequency of use. It was anticipated that the final performance chart programs would be too voluminous to be collectively stored within the HP-41CV memory. This would necessitate using an external mass storage device or executing individual programs piecemeal. Both of these alternatives would have had serious degrading effects, forcing the only other alternative of contracting Hewlett-Packard to hardwire one or more plug-in read-only-memory (ROM) modules containing the NATOPS software.

Fortunately, the majority of programs were reasonable in length. With efficient programming techniques employed, and two external memory modules in series with an extended functions module (total memory of 6.4 Kbytes), it became evident that all programs could be simultaneously stored within the calculator. With this in mind a master program was written which functioned as a software manager which assigned performance charts to key locations (Appendix A), called programs from inexecutable extended memory to the executable work space in main memory, and interactively communicated with the user. In general the master program functioned as a communications system and manager between the user and performance chart software in an interactive and user-friendly mode.

Appendix A contains the simple user instructions to execute any of the 10 listed NATOPS charts desired. With a printer attached a complete performance profile can be executed and printed for any mission plan. Appendix B lists all surface regression equations, flow charts, and program

code. It should be noted that the regression equations can be programmed for use with any capable system. The results presented here are for the H-46D and modified H-46A (with T58-GE-10 engines) NATOPS performance charts referenced in Appendix A. Future modification of these charts would invalidate the performance software for those particular charts.

## V. CONCLUSIONS AND RECOMMENDATIONS

From the results of this thesis it can be concluded that graphical NATOPS performance data can be computerized. To effectively accomplish this, computer oriented numerical regression routines must be utilized to generate closed-form equations.

Once the equations have been derived, computer software can be developed that executes the programs in an expeditious, accurate, and portable fashion. Furthermore, this software can be designed for virtually any type of computer from hand-held programmable calculators to personal computers.

It is recommended that the NATOPS performance software developed in this study be submitted to a fleet squadron or Fleet Replacement Squadron (FRS) for test and evaluation. Since the software can be utilized as is, with off the shelf Hewlett-Packard components, the cost of testing would be minimized. If this software proved to be fleet applicable, Hewlett-Packard should be contracted to develop plug-in application modules which would increase reliability and decrease execution time.

**APPENDIX A**  
**NATOPS PERFORMANCE SOFTWARE USER'S GUIDE**

**A. BASIC USE**

The NATOPS performance software designed for the HP-41CV calculator is simple and expeditious to use. The calculator keyboard configuration is depicted in Figure A.1. As you can see the first top two rows have abbreviated program names under the keys. The exact meaning of each performance chart abbreviation and its NATOPS [Ref. 4] page reference are contained in Table I below.

**TABLE I**  
**NATOPS Performance Chart Reference**

HP-41CV ABBREVIATION	NATOPS CHART TITLE	NATOPS PAGE NUMBER
DA	Density Altitude Chart	11-3
TQAV	Engine Performance Chart (Military Power 100% Nr)	11-5
HIGW	Max Gross Weight for Hovering in Ground Effect	11-9
VTOW	Max Gross Weight for Vertical Takeoff	11-11
HITQ	Torque Required to Hover in Ground Effect	11-12
HOTQ	Torque Required to Hover Out of Ground Effect	11-13
SE/EV	Ability to Maintain Flight One Engine Operating (100% Nr)	11-37
RNG	Max Range (100% Nr)	11-22/3
VNE	Indicated Never Exceed Speed	1-173
END	Max Level Flight Endurance	11-32/3



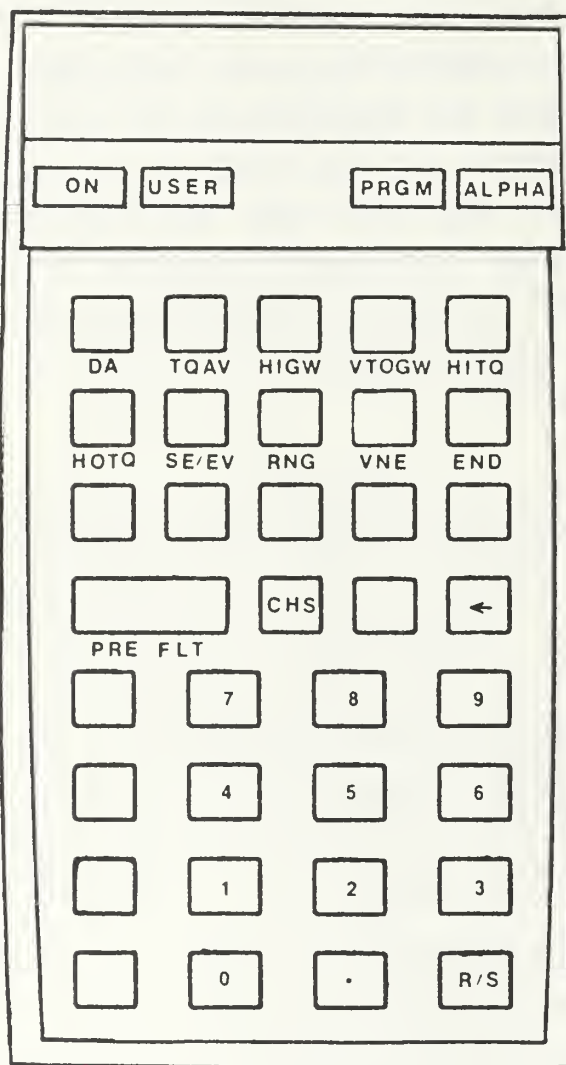


Figure A.1 Hewlett-Packard HP-41CV Calculator

The programs listed in Table I are assigned to the corresponding keys shown in Figure A.1. The key marked "PRE FLT" performs all 10 programs and produces a hard copy of the output. This program requires that a printer is attached. To execute a program follow the steps presented below.

1. Turn the calculator on.
2. Ensure the calculator is in the user mode, if the word user is not visible in the display push the user key.
3. Find the key with the particular performance chart desired and push it. As the program is initiated the calculator will prompt the user for any needed information. The exact prompt meanings are defined below:
  - PA? FT - pressure altitude in ft.
  - OAT? C - outside air temperature in °C.
  - GW? LBS - gross weight in lbs.
  - WIND? KTS - head wind in kts.
  - CLIMB? FPM - climb rate in ft. per min.
  - FUEL? LBS - fuel on board in lbs.
4. Answer the prompt by pushing the corresponding numbered keys until the desired value is seen in the display. If a mistake is made, simply push the key with the horizontal arrow (far right column four keys from the top) and re-enter the number. If the number to be entered is negative (negative OAT), push the key marked CHS after the number has been entered in the display. When the desired number is displayed in the window push the key marked R/S (run/stop, bottom right key).
5. After all the prompts required have been answered the calculator will execute the program. While the calculator is working "PRGM" will be visible in the display. As the calculator generates answers they

are shown in the display. Some charts yield more than one performance parameter, so it is necessary to note each parameter displayed and then push the R/S key to continue execution.

6. Once all performance parameters have been calculated pushing R/S will display "NEXT" which tells the user he has been given all available output and the calculator is ready to execute the next program.
7. Before executing the PRE FLT program ensure the calculator is turned off. With the printer also turned off plug the printer input chord into the only remaining extension port. Turn the calculator and printer on, select the normal mode on the printer, and push the PRE FLT key. All other instructions remain the same.

## **B. GENERAL USER INFORMATION**

The NATOPS software should generate accurate answers within the range of a selected performance chart. If data is entered erroneously, or in excess of a particular chart's range, the output will be in error.

In the cases where a chart has limitations such as density altitude [Ref. 4: p. 11-9], these have been taken into account within the program and the output will tell the user if they exceed that limitation. If the user is ever in doubt as to the validity of the calculator generated performance data, the NATOPS should be consulted.

## **C. INITIAL CALCULATOR PREPARATION**

The basic use instructions assume the user has a calculator that has all the performance software installed. If the user merely has the calculator (with two extended memory modules, and an extended functions module), a card reader,

and the NATOPS software program cards; several steps must be taken before the calculator can be used as described earlier.

1. Become familiar with the HP-41CV owner's manual and all peripherals operating instructions. While the basic user can avoid an in depth knowledge of the system, the initial set up requires someone who is familiar with the hardware and procedures listed in [Refs. 5,6,7].
2. With the extended memory and extended functions modules in their proper ports, and the card reader attached, loading the programs into main and extended memory can begin.
  - Load the following programs into extended memory: HIGW, VTOGW, HITQ, HOTQ, SE/EV, VNE, RNG, ENDA, and ENDB.
  - Load the following programs into main memory (in the order listed): MAIN, QD, DA, and TQAV.
3. Ensure the only programs in main memory are the ones listed above and erase any other programs.
4. Pack the programs in main memory.
5. Execute the program MAIN.

The calculator is now loaded and positioned to the main program. By pressing the user key the performance programs are assigned to their respective key locations and the calculator is ready for program execution.

APPENDIX B  
REGRESSION EQUATIONS AND SOFTWARE DOCUMENTATIONS

This appendix contains all of the regression equations generated for each NATOPS chart, associated flow charts, and resulting computer code. For the most part, the regression equations are listed in a tabular form due to their size. The actual equations are of the form shown in equation 2.1. The  $R^2$  and standard error of estimate for each regression is also listed. The standard error of estimate is the average error expected over one standard deviation of the surface's area. The flow charts use standard symbology and depict the general programming logic but are not detailed in nature. The computer code listings are in the Reverse Polish Notation (RPN) language developed by Hewlett-Packard..

Table II lists all the variables used in the regression equations throughout the programs. Table III lists the programming flags used and their definitions. The following is a listing of memory storage registers and their contents.

REGISTER      VARIABLE/TRANSFORM

00	A
01	A <sup>2</sup>
02	A <sup>3</sup>
03	A <sup>4</sup>
04	B
05	B <sup>2</sup>
06	B <sup>3</sup>
07	B <sup>4</sup>
08	C
09	C <sup>2</sup>
10	C <sup>3</sup>
11	C <sup>4</sup>
12	D
13	D <sup>2</sup>
14	D <sup>3</sup>
15	D <sup>4</sup>
16	E
17	E <sup>2</sup>
18	E <sup>3</sup>
19	E <sup>4</sup>
20	F
21	G
22	scratch

<u>REGISTER</u>	<u>VARIABLE/TRANSFORM</u>
23	scratch
24	scratch
25	scratch
26	scratch
27	scratch
28	scratch
29	scratch
30	scratch
31	scratch

**TABLE II**  
**Variable Definitions**

<u>VARIABLE</u>	<u>DEFINITION</u>
A	(Pressure Altitude)/1000
B	(Outside Air Temperature)/1000
C	(Gross Weight)/1000
D	(Density Altitude)/1000
E	Wind
F	(Fuel)/100
G	(Vertical Climb)/10
H	(Torque Available)/100
I	Standard temperature (END)
J	Base Line Gross Weight No Wind (HIGW)
K	Base Line Gross Weight No Wind (VTOGW)
L	Base Line Gross Weight No Climb (VTOGW)
M	Base Line Average Torque (HITQ)
N	Base Line Average Torque (HOTQ)
P	Base Line Unit Range (RNG)
Q	Unit Range (RNG)
R	Base Line Indicated Airspeed (RNG)
T	Base Line Time (END)
U	Base Line Torque (SE/EV)



TABLE III  
Flag Definitions

FLAG	DEFINITIONS
01	Pre Flt program in execution
02	Do not display register contents
03	Recalculate endurance for new weight (END)
21	Print a hard copy of results

## A. MASTER PROGRAM (MAIN)

1. Equations- This program serves as the software manager and does not contain equations in itself.
2. Flowchart- See Figure B.1.
3. Program listing- See pages 31-32.

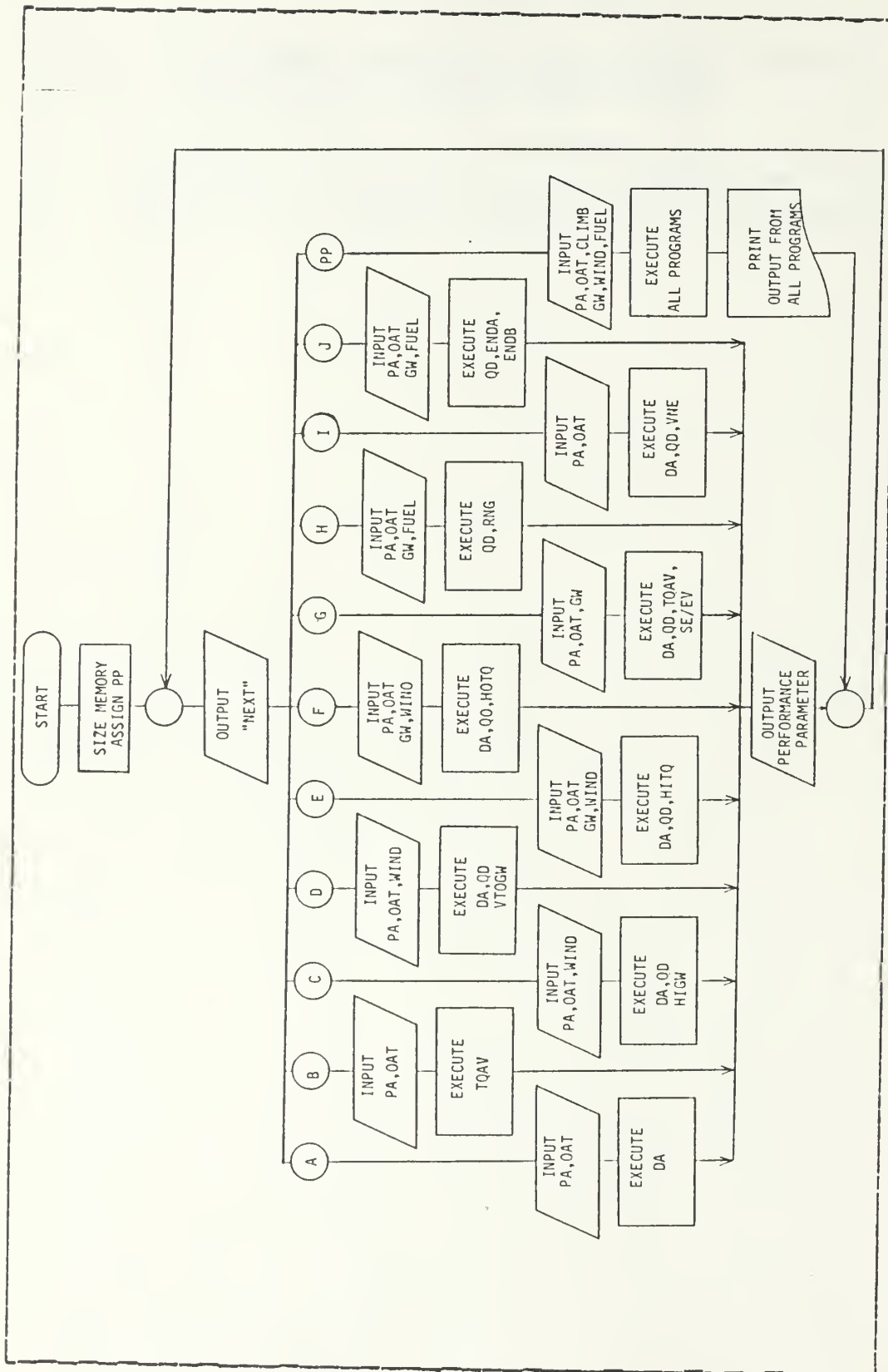


Figure B.1 MAIN Flowchart

01*LBL "MAIN"	51 GTO 13	101 XEQ 11
02 32	52*LBL G	102 RCL 12
03 PSIZE	53 XEQ 09	103 1000
04 41	54 XEQ "TOAV"	104 *
05 "PP"	55 "SE/EV"	105 "DA="
06 PASH	56 GETP	106 ARCL X
07*LBL 13	57 XEQ "SE/EV"	107 ADV
08 ADV	58 PROMPT	108 FFA
09 ADV	59 GTO 13	109 XEQ "TOAV"
10 FIX 0	60*LBL H	110 FFA
11 "NEXT"	61 XEQ 07	111 "HIGH"
12 PROMPT	62 XEQ 11	112 GETP
13*LBL A	63 "PNG"	113 XEQ "HIGH"
14 XEQ 06	64 GETP	114 FFA
15 XEQ "DA"	65 XEQ "PNG"	115 "VTOGW"
16 ADV	66 PROMPT	116 GETP
17 PROMPT	67 GTO 13	117 XEQ "VTOGW"
18 GTO 13	68*LBL I	118 FFA
19*LBL B	69 XEQ 09	119 "HIT0"
20 XEQ 06	70 "VNE"	120 GETP
21 XEQ "TOAV"	71 GETP	121 XEQ "HIT0"
22 PROMPT	72 XEQ "VNE"	122 FFA
23 GTO 13	73 PROMPT	123 "HOTO"
24*LBL C	74 GTO 13	124 GETP
25 XEQ 06	75*LBL J	125 XEQ "HOTO"
26 "HIGH"	76 XEQ 07	126 FFA
27 GETP	77 XEQ 11	127 "SE/EV"
28 XEQ "HIGH"	78 "ENDA"	128 GETP
29 PROMPT	79 GETP	129 XEQ "SE/EV"
30 GTO 13	80 XEQ "ENDA"	130 FFA
31*LBL D	81 PROMPT	131 "PNG"
32 XEQ 06	82 "END0"	132 GETP
33 "VTOGW"	83 GETP	133 XEQ "PNG"
34 GETP	84 XEQ "END0"	134 FFA
35 XEQ "VTOGW"	85 PROMPT	135 "VNE"
36 PROMPT	86 GTO 13	136 GETP
37 GTO 13	87*LBL "PP"	137 XEQ "VNE"
38*LBL E	88 FS? 21	138 FFA
39 XEQ 10	89 GTO 14	139 "ENDA"
40 "HIT0"	90 "PTR REQ"	140 GETP
41 GETP	91 PROMPT	141 XEQ "ENDA"
42 XEQ "HIT0"	92 GTO 13	142 FFA
43 PROMPT	93*LBL 14	143 "END0"
44 GTO 13	94 SF 01	144 GETP
45*LBL F	95 XEQ 10	145 XEQ "END0"
46 XEQ 10	96 "CLIME? FPM"	146 FFA
47 "HOTO"	97 PROMPT	147 CF 01
48 GETP	98 10	148 GTO 13
49 XEQ "HOTO"	99 /	149*LBL 06
50 PROMPT	100 GTO 21	150 XEQ 01

151 XEQ 02	201 RTN
152 RTN	202*LBL 04
153*LBL 07	203 RCL 12
154 XEQ 06	204 13.015
155 XEQ 03	205 XEQ "QD"
156 RTN	206 RTN
157*LBL 08	207*LBL 05
158 SF 02	208 "WIND? KTS"
159 XEQ 06	209 PROMPT
160 XEQ 05	210 STO 16
161 XEQ "DA"	211 17.019
162 CF 02	212 XEQ "QD"
163 RTN	213 RTN
164*LBL 09	214*LBL 11
165 SF 02	215 "FUEL? LBS"
166 FS? 01	216 PROMPT
167 CF 02	217 100
168 XEQ 07	218 /
169 XEQ "DA"	219 STO 20
170 XEQ 04	220 END
171 CF 02	
172 RTN	
173*LBL 10	
174 XEQ 09	
175 XEQ 05	
176 RTN	01*LBL "QD"
177*LBL 01	02 STO T
178 "PA? FT"	03 X/Y
179 PROMPT	04 ENTER↑
180 1000	05 ENTER↑
181 /	06 X12
182 STO 00	07*LBL 12
183 01.003	08 STO IND T
184 XEQ "QD"	09 *
185 RTN	10 ISG T
186*LBL 02	11 GTO 12
187 "OAT? C"	12 END
188 PPROMPT	
189 STO 04	
190 05.007	
191 XEQ "QD"	
192 RTN	
193*LBL 03	
194 "GW? LBS"	
195 PPROMPT	
196 1000	
197 /	
198 STO 08	
199 09.011	
200 XEQ "QD"	

## B. DENSITY ALTITUDE (DA)

1. Equations-  $DA = (1 - a \cdot 234711) / 6.863 \times 10^{-3}$

where  $a = b/c$

and  $b = [1 - 6.863 \times 10^{-3} (A)]^{5.260559}$

and  $c = (273.15 + B) / 288.15$

2. Flowchart- See Figure B.2.

3. Program listing- See page 35.



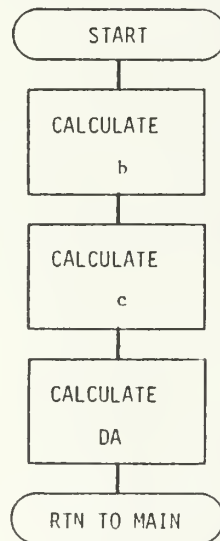


Figure B.2 DA Flowchart

```

01 LBL "DA"
02 RCL 00
03 6.863 E-3
04 *
05 CHS
06 1
07 +
08 5.260559
09 Y↑X
10 RCL 04
11 273.15
12 +
13 288.15
14 /
15 /
16 .234711
17 Y↑X
18 CHS
19 1
20 +
21 6.863 E-3
22 /
23 STO 12
24 FST 02
25 RTN
26 1000
27 *
28 "DA="
29 AFCL X
30 END

```

### C. ENGINE PERFORMANCE (TQAV)

#### 1. Equation/Fit statistics-

Regression equation- For Figure 11-1A  
chart [Ref. 4 p. 11-5].

$$R^2 = .99936$$

Standard error of estimate = .539449 kts.

<u>VARIABLE/ TRANSFORM</u>	<u>REGRESSION COEFFICIENT</u>
INTERCEPT	104.758
A	-3.56893
B	-.394746
A <sup>4</sup> B <sup>2</sup>	-.171715X10 <sup>-7</sup>
A <sup>2</sup>	.0324431
A <sup>2</sup> B	-.000340744
A <sup>2</sup> B <sup>2</sup>	.0000147638
A <sup>2</sup> B <sup>3</sup>	.144471X10 <sup>-6</sup>
AB	.0107422
AB <sup>4</sup>	-.346277X10 <sup>-7</sup>
B <sup>2</sup>	-.00809738
B <sup>3</sup>	-.0000582075
B <sup>4</sup>	.189613X10 <sup>-5</sup>

2. Flowchart- See Figure B.3.

3. Program listing- See page 38.

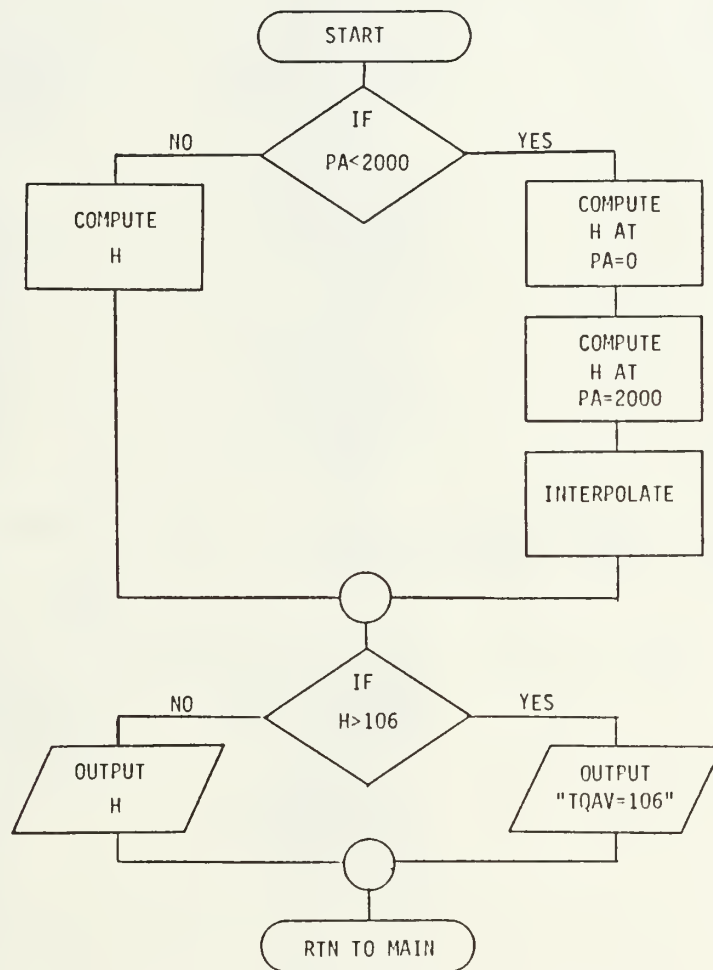


Figure B.3 TQAV Flowchart

01*LBL "TQAV"	51 2.0	101 RCL 01
02 RCL 00	52 /	102 RCL 04
03 STO 25	53 CHS	103 *
04 2.0	54 *	104 -.00034074
05 X<Y?	55 RCL 23	105 *
06 GT0 05	56 +	106 +
07 XEQ 01	57*LBL 10	107 RCL 01
08 GT0 10	58 106.0	108 RCL 05
09*LBL 05	59 X<>Y	109 *
10 -5.0	60 X<Y?	110 .147638 E-4
11 RCL 04	61 GT0 11	111 *
12 X<=Y?	62 10	112 +
13 GT0 02	63 /	113 RCL 01
14 15.0	64 STO 22	114 RCL 06
15 RCL 04	65 FSZ 02	115 +
16 X<=Y?	66 RTN	116 .144471 E-6
17 GT0 03	67 10	117 *
18 60	68 *	118 +
19 +	69 "TQAV="	119 RCL 00
20 -.8625	70 ARCL X	120 RCL 04
21 *	71 ADV	121 *
22 162.6875	72 PTN	122 .0107422
23 +	73*LBL 11	123 *
24 STO 23	74 10.6	124 +
25 GT0 07	75 STO 22	125 RCL 00
26*LBL 03	76 FSZ 02	126 RCL 07
27 60	77 RTN	127 *
28 +	78 "TQAV=106"	128 -.346277 E-7
29 -.4	79 ADV	129 *
30 *	80 PTN	130 +
31 128	81*LBL 01	131 RCL 05
32 +	82 104.758	132 -.00009738
33 STO 23	83 RCL 00	133 *
34 GT0 07	84 -3.56893	134 +
35*LBL 02	85 *	135 RCL 00
36 106.0	86 +	136 -.582075 E-4
37 STO 23	87 RCL 04	137 *
38*LBL 07	88 -.394746	138 +
39 2.0	89 *	139 RCL 07
40 STO 00	90 +	140 .109613 E-5
41 X12	91 RCL 03	141 *
42 STO 01	92 RCL 05	142 +
43 X12	93 *	143 END
44 STO 03	94 -.171715 E-7	
45 XEQ 01	95 *	
46 STO 24	96 +	
47 CHS	97 RCL 01	
48 RCL 23	98 .0324431	
49 +	99 *	
50 RCL 25	100 +	

#### D. MAX GROSS WEIGHT FOR HOVERING (HIGH)

##### 1. Equation/Fit statistics-

Regression equation- For Figure 11-4  
top chart [Ref. 4 p. 11-9].

$R^2 = .99888$

Standard error of estimate = 128.142 lbs.

<u>VARIABLE/ TRANSFORM</u>	<u>REGRESSION COEFFICIENT</u>
INTERCEPT	28.8369
B	-.104947
A	-.957611
B <sup>4</sup>	.236917X10 <sup>-6</sup>
AB <sup>4</sup>	.738596X10 <sup>-7</sup>
A <sup>2</sup> B <sup>4</sup>	-.108756X10 <sup>-7</sup>
A <sup>3</sup> B <sup>4</sup>	.547916X10 <sup>-9</sup>
AB <sup>3</sup>	-.231012X10 <sup>-5</sup>
A <sup>2</sup> B <sup>3</sup>	.167621X10 <sup>-6</sup>
B <sup>2</sup>	-.00209967
A <sup>2</sup> B <sup>2</sup>	.000015347
A <sup>3</sup> B <sup>2</sup>	-.108395X10 <sup>-5</sup>
A <sup>2</sup> B	.000201287
A <sup>4</sup> B	-.852947X10 <sup>-6</sup>
A <sup>2</sup>	.00815863

Regression equation- For Figure 11-4  
bottom chart [Ref. 4 p. 11-9].

$R^2 = .99993$

Standard error of estimate = 19.776 lbs.

<u>VARIABLE/ TRANSFORM</u>	<u>REGRESSION COEFFICIENT</u>
INTERCEPT	.128617
J	.990746
E <sup>2</sup> J	.000043718
EJ	.00283739
J <sup>4</sup>	.3069X10 <sup>-6</sup>

2. Flowchart- See Figure B.4.

3. Program listing- See page 41.



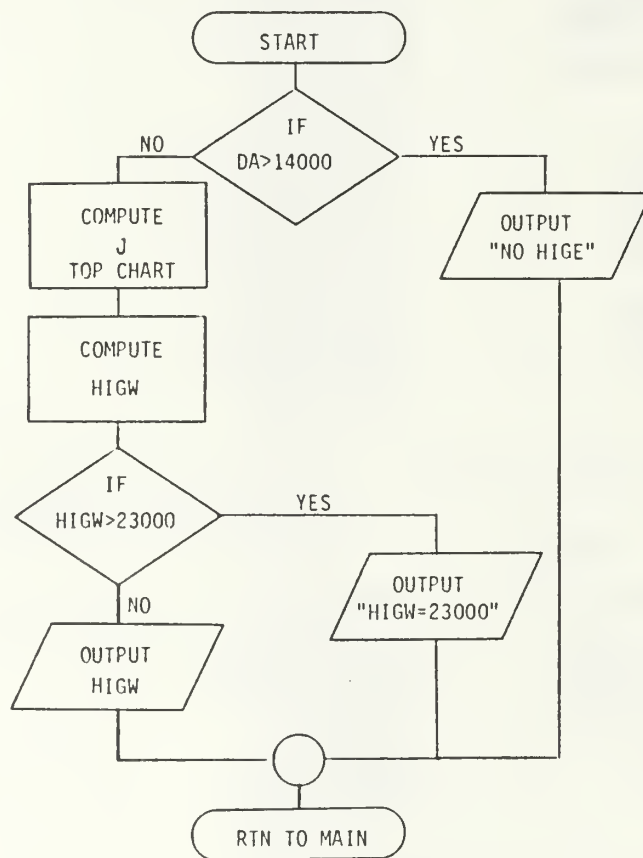


Figure B.4 HIGW Flowchart

01*LBL "HIGH"	51 *	101 +
02 RCL 12	52 +	102 RCL 23
03 14	53 RCL 05	103 4
04 X<Y?	54 -.00209967	104 Y↑X
05 GT0 01	55 *	105 .3069 E-6
06 "NO HIGH"	56 +	106 *
07 ADV	57 RCL 05	107 +
08 PTN	58 RCL 01	108 23.0
09*LBL 01	59 *	109 X<=Y?
10 28.8369	60 .15347 E-4	110 GT0 03
11 RCL 04	61 *	111 X<>Y
12 -.104947	62 +	112 1000
13 *	63 RCL 05	113 *
14 +	64 RCL 02	114 "HIGH="
15 RCL 00	65 *	115 ARCL X
16 -.957611	66 -.108395 E-5	116 ADV
17 *	67 *	117 PTN
18 +	68 +	118*LBL 03
19 RCL 07	69 RCL 04	119 "HIGH=23.000"
20 .236917 E-6	70 RCL 01	120 ADV
21 *	71 *	121 .END.
22 +	72 .000201287	
23 RCL 07	73 *	
24 RCL 00	74 +	
25 *	75 RCL 04	
26 .738596 E-7	76 RCL 03	
27 *	77 *	
28 +	78 -.052947 E-6	
29 RCL 07	79 *	
30 RCL 01	80 +	
31 *	81 RCL 01	
32 -.108756 E-7	82 .00015863	
33 *	83 *	
34 +	84 +	
35 RCL 07	85 GT0 23	
36 RCL 02	86 .990746	
37 *	87 *	
38 .547916 E-9	88 .130617	
39 *	89 +	
40 +	90 RCL 17	
41 RCL 06	91 RCL 23	
42 RCL 00	92 *	
43 *	93 .43718 E-4	
44 -.231012 E-5	94 *	
45 *	95 +	
46 +	96 RCL 16	
47 RCL 06	97 RCL 23	
48 RCL 01	98 *	
49 *	99 .00283739	
50 .167621 E-6	100 *	

# E. MAX GROSS WEIGHT FOR VERTICAL TAKEOFF (VTOGW)

## 1. Equation/Fit statistics-

Regression equation- For Figure 11-5  
top chart discontinuity  
curve (CPA) [Ref. 4 p. 11-11].

$R^2 = .99923$

Standard error of estimate = 81.257 lbs.

<u>VARIABLE/ TRANSFORM</u>	<u>REGRESSION COEFFICIENT</u>
INTERCEPT	3.72796
B	-.0954314
B <sup>2</sup>	-.00188251
B <sup>3</sup>	-.0000596998
B <sup>4</sup>	-.608172X10 <sup>-6</sup>

Regression equation- For Figure 11-5  
top chart left of  
discontinuity [Ref. 4 p. 11-11].

$R^2 = .99919$

Standard error of estimate = 96.041 lbs.

<u>VARIABLE/ TRANSFORM</u>	<u>REGRESSION COEFFICIENT</u>
INTERCEPT	26.1925
B	-.117656
A	-1.04142
B <sup>4</sup>	.311223X10 <sup>-6</sup>
A <sup>4</sup> B <sup>4</sup>	.876216X10 <sup>-11</sup>
B <sup>3</sup>	-.734593X10 <sup>-5</sup>
A <sup>4</sup> B <sup>3</sup>	.358246X10 <sup>-9</sup>
B <sup>2</sup>	-.00147462
AB <sup>2</sup>	.0000495106
A <sup>2</sup> B <sup>2</sup>	-.451883X10 <sup>-5</sup>
AB	.0060469
A <sup>2</sup> B	-.000282418
A <sup>2</sup>	.0268048
A <sup>3</sup>	-.000633067

Regression equation- For Figure 11-5  
top chart right of  
discontinuity [Ref. 4 p. 11-11].

$R^2 = .99944$

Standard error of estimate = 12.521 lbs.

<u>VARIABLE/ TRANSFORM</u>	<u>REGRESSION COEFFICIENT</u>
INTERCEPT	23.346
B	-.0155989
A	-.1907
B <sup>4</sup>	-.219767X10 <sup>-6</sup>
AB <sup>4</sup>	.389472X10 <sup>-8</sup>
B <sup>3</sup>	-.769256X10 <sup>-5</sup>
B <sup>2</sup>	.000147492
A <sup>2</sup>	-.00128983

Regression equation- For Figure 11-5  
middle chart [Ref. 4 p. 11-11].

$R^2 = .99996$

Standard error of estimate = 32.545 lbs.

<u>VARIABLE/ TRANSFORM</u>	<u>REGRESSION COEFFICIENT</u>
INTERCEPT	.00559456
E	-.0756063
K	.999707
E <sup>3</sup>	-.164715X10 <sup>-4</sup>
E <sup>2</sup> K	.00038988
E <sup>2</sup> K <sup>2</sup>	-.250156X10 <sup>-4</sup>
E <sup>2</sup> K <sup>4</sup>	.234975X10 <sup>-7</sup>
EK	.0103111
EK <sup>4</sup>	-.220855X10 <sup>-6</sup>

Regression equation- For Figure 11-5  
bottom chart [Ref. 4 p. 11-11].

$R^2 = .99996$

Standard error of estimate = 24.736 lbs.

<u>VARIABLE/ TRANSFORM</u>	<u>REGRESSION COEFFICIENT</u>
INTERCEPT	.0278589
L	.998241
GL	-.00189451
GL <sup>3</sup>	.425897X10 <sup>-5</sup>
GL <sup>4</sup>	-.140897X10 <sup>-6</sup>

2. Flowchart- See Figure B.5.

3. Program listing- See page 45-46.

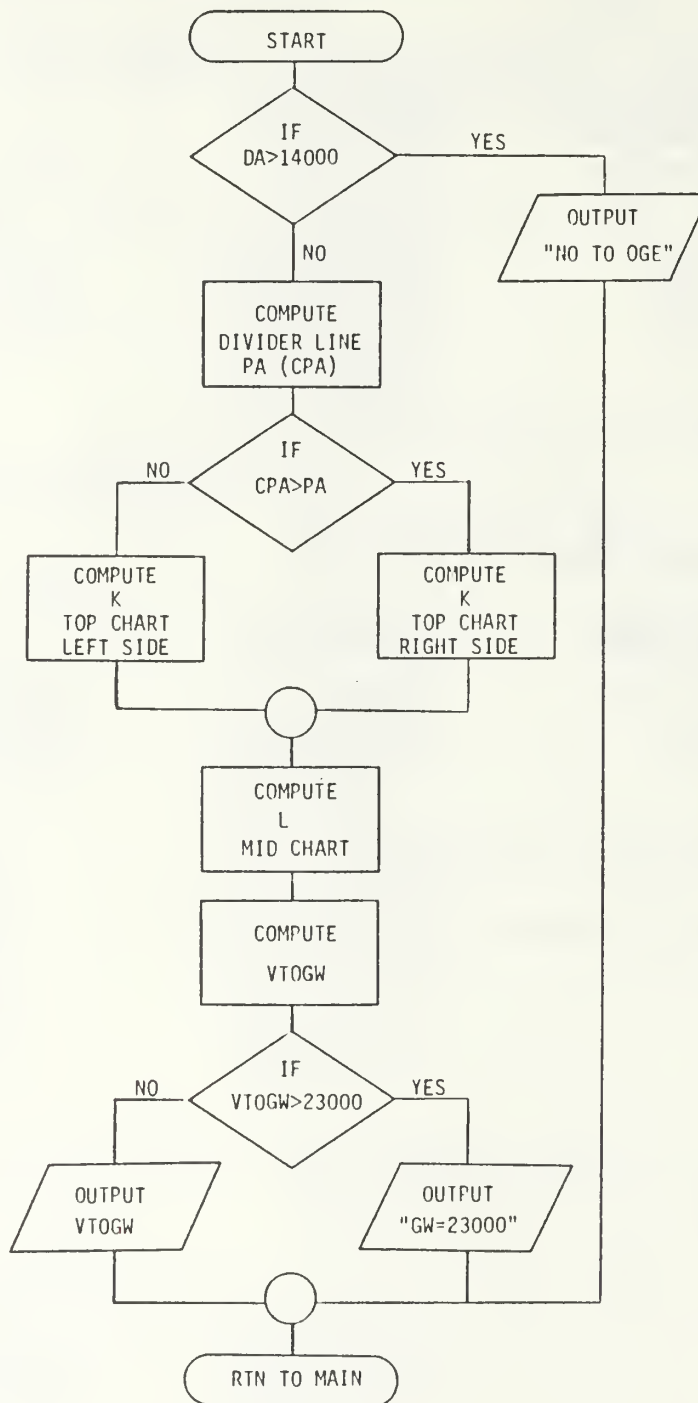


Figure B.5 VTOGW Flowchart

01*LBL "VTOGW"	51 +	101 -.00063067
02 FS? 01	52 RCL 07	102 *
03 GT0 09	53 RCL 03	103 +
04 "CLIMB? FPM"	54 *	104 GT0 05
05 PROMPT	55 .876216 E-11	105*LBL 03
06 10	56 *	106 23.346
07 /	57 +	107 RCL 04
08 STO 21	58 RCL 06	108 -.0155989
09*LBL 09	59 -.734593 E-5	109 *
10 RCL 12	60 *	110 +
11 14	61 +	111 RCL 06
12 X>Y?	62 RCL 06	112 -.1907
13 GT0 01	63 RCL 03	113 *
14 "NO VTO OGE"	64 *	114 +
15 ADV	65 .358246 E-9	115 RCL 07
16 PTN	66 *	116 -.219767 E-6
17*LBL 01	67 +	117 *
18 3.72796	68 RCL 05	118 +
19 RCL 04	69 -.00147462	119 RCL 07
20 -.0954314	70 *	120 RCL 06
21 *	71 +	121 *
22 +	72 RCL 05	122 .389472 E-8
23 RCL 05	73 RCL 00	123 +
24 -.00188251	74 *	124 +
25 *	75 .495106 E-4	125 RCL 06
26 +	76 *	126 -.769256 E-5
27 RCL 06	77 +	127 *
28 -.596998 E-4	78 RCL 05	128 +
29 *	79 RCL 01	129 RCL 05
30 +	80 *	130 .000147492
31 RCL 07	81 -.451883 E-5	131 *
32 -.600172 E-6	82 *	132 +
33 *	83 +	133 RCL 01
34 +	84 RCL 04	134 -.00128983
35 STO 23	85 RCL 00	135 *
36 RCL 00	86 *	136 +
37 X<=Y?	87 .0000469	137*LBL 05
38 GT0 03	88 *	138 STO 24
39 26.1925	89 +	139 X12
40 RCL 04	90 RCL 04	140 STO 25
41 -.117656	91 RCL 01	141 X12
42 *	92 *	142 STO 26
43 +	93 -.000282418	143 .00559456
44 RCL 00	94 *	144 RCL 16
45 -1.04142	95 +	145 -.0756063
46 *	96 RCL 01	146 *
47 +	97 .0268048	147 +
48 RCL 07	98 *	148 RCL 24
49 .311223 E-6	99 +	149 .999707
50 *	100 RCL 02	150 *



151 +	201 *
152 RCL 18	202 -.0018941
153 -.164715 E-4	203 *
154 *	204 +
155 +	205 RCL 21
156 RCL 17	206 RCL 25
157 RCL 24	207 *
158 *	208 .425897 E-5
159 .00038988	209 *
160 *	210 +
161 +	211 RCL 21
162 RCL 17	212 RCL 26
163 RCL 25	213 *
164 *	214 -.146897 E-6
165 -.250156 E-4	215 *
166 *	216 +
167 +	217 23.0
168 RCL 17	218 X<=Y?
169 RCL 26	219 GTO 04
170 *	220 X<>Y
171 .234975 E-7	221 1000
172 *	222 *
173 +	223 "VTO GW="
174 RCL 16	224 RRCL X
175 RCL 24	225 ADV
176 *	226 RTN
177 .0103111	227 *LBL 04
178 *	228 "VTO GW=23.000"
179 +	229 ADV
180 RCL 16	230 .END.
181 RCL 26	
182 *	
183 -.220055 E-6	
184 *	
185 +	
186 STO 24	
187 ENTER↑	
188 ENTER↑	
189 X↑2	
190 *	
191 STO 25	
192 *	
193 STO 26	
194 .0278509	
195 RCL 24	
196 .998241	
197 *	
198 +	
199 RCL 21	
200 RCL 24	

## F. TORQUE REQUIRED TO HOVER IN GROUND EFFECT (HITQ)

### 1. Equations/Fit statistics-

Regression equation- For Figure 11-6  
top chart [Ref. 4 p. 11-12].

$$R^2 = .99941$$

Standard error of estimate = .445612 % tg.

<u>VARIABLE/ TRANSFORM</u>	<u>REGRESSION COEFFICIENT</u>
INTERCEPT	-1.4252
C	3.17576
C <sup>4</sup>	.29445X10 <sup>-4</sup>
C <sup>4</sup> D <sup>2</sup>	.862219X10 <sup>-7</sup>
C <sup>3</sup> D	.431755X10 <sup>-4</sup>
D <sup>3</sup>	.000628288

Regression equation- For Figure 11-6  
bottom chart [Ref. 4 p. 11-12].

$$R^2 = .99997$$

Standard error of estimate = .123506 % tg.

<u>VARIABLE/ TRANSFORM</u>	<u>REGRESSION COEFFICIENT</u>
INTERCEPT	-.0376377
E	.694891
M	1.00055
E <sup>4</sup>	-.163135X10 <sup>-5</sup>
E <sup>4</sup> M <sup>2</sup>	.100327X10 <sup>-9</sup>
E <sup>2</sup>	-.00298623
EM	-.0296401
EM <sup>2</sup>	.000268863
EM <sup>4</sup>	-.647012X10 <sup>-8</sup>

2. Flowchart- See Figure B.6.

3. Program listing- See page 49.

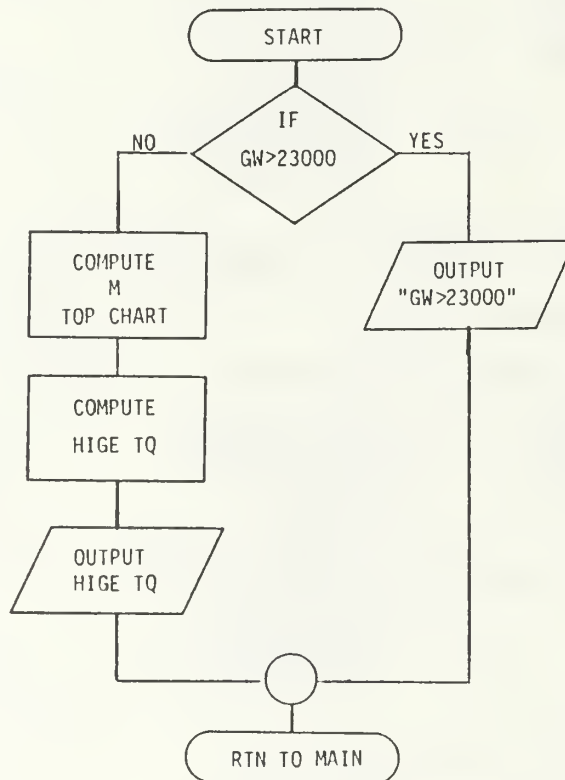


Figure B.6 HITQ Flowchart

```

01*LBL "HIT0"
02 23
03 RCL 08
04 X<=Y?
05 GT0 03
06 "GM">23.000"
07 ADV
08 FTH
09*LBL 03
10 -1.4252
11 RCL 08
12 3.17576
13 *
14 +
15 RCL 11
16 .2945 E-4
17 *
18 +
19 RCL 11
20 RCL 13
21 *
22 .862219 E-7
23 *
24 +
25 RCL 10
26 RCL 12
27 *
28 .431755 E-4
29 *
30 +
31 RCL 14
32 .000628288
33 *
34 +
35 STO 23
36 X↑2
37 STO 24
38 X↑2
39 STO 25
40 -.037637
41 RCL 16
42 .694891
43 *
44 +
45 RCL 23
46 1.00055
47 *
48 +
49 RCL 19
50 -.163135 E-5

```

```

51 *
52 +
53 RCL 19
54 RCL 24
55 *
56 .100327 E-9
57 *
58 +
59 RCL 17
60 -.00298623
61 *
62 +
63 RCL 16
64 RCL 23
65 *
66 -.0296401
67 *
68 +
69 RCL 16
70 RCL 24
71 *
72 .000268963
73 *
74 +
75 RCL 16
76 RCL 25
77 *
78 -.647012 E-2
79 *
80 +
81 "HIGE T0="
82 APCL X
83 ADV
84 .END.

```

G. TORQUE REQUIRED TO HOVER OUT OF GROUND EFFECT (HOTQ)

1. Equations/Fit statistics-

Regression equation- For Figure 11-7  
top chart [Ref. 4 p. 11-13].

$$R^2 = .99987$$

Standard error of estimate = .215589 % tq.

<u>VARIABLE/ TRANSFORM</u>	<u>REGRESSION COEFFICIENT</u>
INTERCEPT	15.0892
D	.108012
C <sup>4</sup> D	.18747X10 <sup>-5</sup>
C <sup>4</sup> D <sup>4</sup>	-.520378X10 <sup>-8</sup>
C <sup>3</sup>	-.00353622
C <sup>3</sup> D <sup>4</sup>	.123336X10 <sup>-6</sup>
C <sup>2</sup>	.226524
CD <sup>2</sup>	.00162427
D <sup>3</sup>	-.00265822

Regression equation- For Figure 11-7  
bottom chart [Ref. 4 p. 11-13].

$$R^2 = .99978$$

Standard error of estimate = .292877 % tq.

<u>VARIABLE/ TRANSFORM</u>	<u>REGRESSION COEFFICIENT</u>
INTERCEPT	-.0523486
E	-.30622
N	1.00117
E <sup>4</sup> N <sup>2</sup>	-.434411X10 <sup>-9</sup>
EN <sup>2</sup>	-.266181X10 <sup>-4</sup>

2. Flowchart- See Figure B.7.

3. Program listing- See page 52.

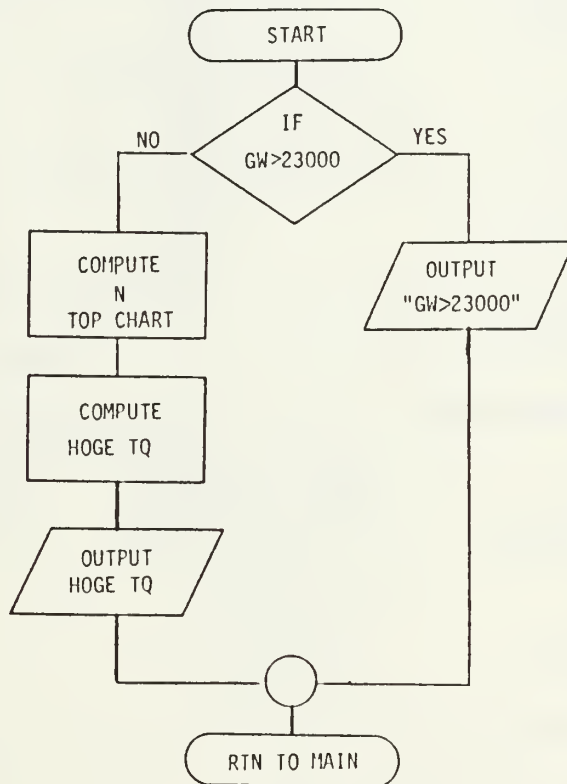


Figure B.7 HOTQ Flowchart



01+LBL "HOT0"	51 STO 23
02 23	52 X12
03 RCL 08	53 STO 24
04 X<=Y?	54 -.0523486
05 GTO 03	55 RCL 16
06 "GW>23.000"	56 -.30622
07 ADV	57 *
08 RTN	58 +
09+LBL 03	59 RCL 23
10 15.0092	60 1.00117
11 RCL 12	61 *
12 .100012	62 +
13 *	63 RCL 19
14 +	64 RCL 24
15 RCL 11	65 *
16 RCL 12	66 -.43441 E-9
17 *	67 *
18 .18747 E-5	68 +
19 *	69 RCL 16
20 +	70 RCL 24
21 RCL 11	71 *
22 RCL 15	72 -.266181 E-4
23 *	73 *
24 -.520378 E-8	74 +
25 *	75 "H0GE T0="
26 +	76 ARCL X
27 RCL 10	77 ADV
28 -.0035362	78 .END.
29 *	
30 +	
31 RCL 10	
32 RCL 15	
33 *	
34 .123336 E-6	
35 *	
36 +	
37 RCL 09	
38 .226524	
39 *	
40 +	
41 RCL 08	
42 RCL 13	
43 *	
44 .00162427	
45 *	
46 +	
47 RCL 14	
48 -.00265022	
49 *	
50 +	

## H. MAXIMUM RANGE (RNG)

### 1. Equations/Fit statistics-

Regression equation- For Figure 11-13  
bottom right [Ref. 4 p. 11-22].

$$R^2 = .99773$$

Standard error of estimate = .000884 nm/lb fuel.

<u>VARIABLE/ TRANSFORM</u>	<u>REGRESSION COEFFICIENT</u>
INTERCEPT	.1383
A	.00187702
C	-.00218126
A <sup>3</sup>	-.000027957
AC <sup>3</sup>	-.62102X10 <sup>-7</sup>
A <sup>4</sup> C <sup>6</sup>	.930331X10 <sup>-14</sup>
A <sup>6</sup> C <sup>2</sup>	-.300259X10 <sup>-10</sup>
A <sup>5</sup> C	.106168X10 <sup>-7</sup>
A <sup>3</sup> C <sup>6</sup>	-.279396X10 <sup>-12</sup>
A <sup>2</sup>	.000307637

Regression equation- For Figure 11-13  
bottom left [Ref. 4 p. 11-22].

$$R^2 = .99995$$

Standard error of estimate = .000166 nm/lb fuel.

<u>VARIABLE/ TRANSFORM</u>	<u>REGRESSION COEFFICIENT</u>
INTERCEPT	-.423343X10 <sup>-4</sup>
P	1.00044
B	-.403071X10 <sup>-4</sup>
P <sup>4</sup> B	.277347
P <sup>4</sup> B <sup>4</sup>	-.49131X10 <sup>-5</sup>
P <sup>3</sup> B	-.0402217
P <sup>3</sup> B <sup>4</sup>	.80486X10 <sup>-6</sup>
B <sup>4</sup>	-.421314X10 <sup>-9</sup>

Regression equation- For Figure 11-14  
chart [Ref. 4 p. 11-23].

$$R^2 = .99991$$

Standard error of estimate = 1.045573 nm.

<u>VARIABLE/ TRANSFORM</u>	<u>REGRESSION COEFFICIENT</u>
INTERCEPT	.459586
F	.227375
FQ	99.6167

Regression equation- For Figure 11-13  
middle right [Ref. 4 p. 11-22].

$R^2 = .99676$

Standard error of estimate = .703488 kts.

<u>VARIABLE/ TRANSFORM</u>	<u>REGRESSION COEFFICIENT</u>
INTERCEPT	116.811
A	-2.20562
A <sup>3</sup> C <sup>2</sup>	.0000960635
A <sup>3</sup> C <sup>4</sup>	-.128465X10 <sup>-6</sup>
A <sup>2</sup> C <sup>3</sup>	-.0000375032
C <sup>2</sup>	.0333256
A <sup>6</sup> C <sup>5</sup>	-.121685X10 <sup>-10</sup>
A <sup>6</sup> C <sup>6</sup>	.491492X10 <sup>-12</sup>
AC <sup>5</sup>	.404972X10 <sup>-5</sup>
AC <sup>6</sup>	-.174029X10 <sup>-6</sup>

Regression equation- For Figure 11-13  
middle left [Ref. 4 p. 11-22].

$R^2 = .99839$

Standard error of estimate = .870905 kts.

<u>VARIABLE/ TRANSFORM</u>	<u>REGRESSION COEFFICIENT</u>
INTERCEPT	51.8923
B	-3.6787
R <sup>4</sup>	-.403206X10 <sup>-6</sup>
R <sup>4</sup> B	-.261757X10 <sup>-8</sup>
R <sup>4</sup> B <sup>3</sup>	-.286464X10 <sup>-12</sup>
R <sup>3</sup>	.0000882727
R <sup>2</sup> B <sup>2</sup>	-.165604X10 <sup>-5</sup>
RB	.0330258
RB <sup>2</sup>	.00045386
B <sup>2</sup>	-.0356287

2. Flowchart- See Figure B.8.

3. Program listing- See pages 56-57.

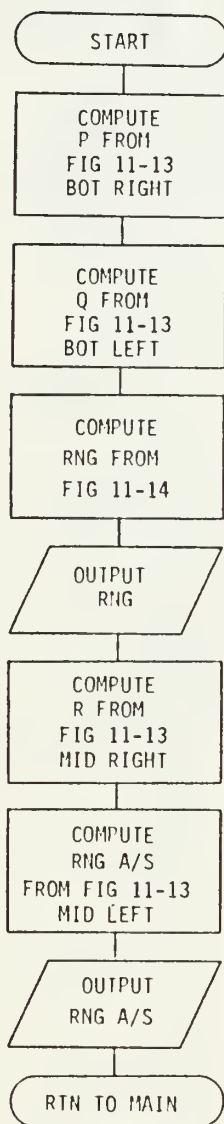


Figure B.8 RNG Flowchart

01*LBL "RNG"	51 -.279396 E-12	101 *
02*LBL 01	52 *	102 .459586
03 RCL 02	53 +	103 +
04 X12	54 RCL 01	104 RCL 00
05 STO 23	55 .000307673	105 .227375
06 RCL 10	56 *	106 *
07 X12	57 +	107 +
08 STO 24	58 STO 25	108 "MAX RNG="
09 .1383	59 26.028	109 ARCL X
10 RCL 00	60 XEQ "QD"	110 FSZ 01
11 .00107702	61 -.423343 E-4	111 GTO 03
12 *	62 RCL 25	112 ADV
13 +	63 1.00044	113 PROMPT
14 RCL 00	64 *	114 GTO 04
15 -.00210126	65 +	115*LBL 03
16 *	66 RCL 04	116 ADV
17 +	67 -.403071 E-4	117 FRA
18 RCL 02	68 *	118*LBL 04
19 -.27957 E-4	69 +	119 116.011
20 *	70 RCL 20	120 RCL 00
21 +	71 RCL 04	121 -2.20562
22 RCL 00	72 *	122 *
23 RCL 10	73 .277347	123 +
24 *	74 *	124 RCL 02
25 -.62102 E-7	75 +	125 RCL 00
26 *	76 RCL 20	126 *
27 +	77 RCL 07	127 .960635 E-4
28 RCL 03	78 *	128 *
29 RCL 24	79 -.49131 E-5	129 +
30 *	80 *	130 RCL 02
31 .930331 E-14	81 +	131 RCL 11
32 *	82 RCL 27	132 *
33 +	83 RCL 04	133 -.128465 E-6
34 RCL 23	84 *	134 *
35 RCL 09	85 -.0402217	135 +
36 *	86 *	136 RCL 01
37 -.300259 E-10	87 +	137 RCL 10
38 *	88 RCL 27	138 *
39 +	89 RCL 07	139 -.375032 E-4
40 RCL 00	90 *	140 *
41 5	91 .80486 E-6	141 +
42 Y1X	92 *	142 RCL 00
43 RCL 00	93 +	143 .0333256
44 *	94 RCL 07	144 *
45 .106168 E-7	95 -.421314 E-9	145 +
46 *	96 *	146 RCL 23
47 +	97 +	147 RCL 00
48 RCL 02	98 RCL 20	148 5
49 RCL 24	99 *	149 Y1X
50 *	100 99.6167	150 *

151 -.121695 E-10	201 +
152 *	202 RCL 26
153 +	203 RCL 05
154 RCL 23	204 *
155 RCL 24	205 -.165604 E-5
156 *	206 *
157 .491492 E-12	207 +
158 *	208 RCL 04
159 +	209 RCL 25
160 RCL 00	210 *
161 RCL 00	211 .0330258
162 5	212 *
163 Y↑X	213 +
164 *	214 RCL 25
165 .404972 E-5	215 RCL 05
166 *	216 *
167 +	217 .00045386
168 RCL 00	218 *
169 RCL 24	219 +
170 *	220 RCL 05
171 -.174029 E-6	221 -.0356287
172 *	222 *
173 +	223 +
174 STO 25	224 "RNG A/S="
175 26.028	225 ARCL X
176 XEQ "QD"	226 ADV
177 51.8923	227 .END.
178 RCL 04	
179 -3.6787	
180 *	
181 +	
182 RCL 28	
183 -.403206 E-6	
184 *	
185 +	
186 RCL 28	
187 RCL 04	
188 *	
189 -.261757 E-8	
190 *	
191 +	
192 RCL 28	
193 RCL 06	
194 *	
195 -.286464 E-12	
196 *	
197 +	
198 RCL 27	
199 .802727 E-4	
200 *	

# I. MAXIMUM LEVEL FLIGHT ENDURANCE (END)

## 1. Equations/Fit statistics-

Regression equation- For Figure 11-21  
bottom chart [Ref. 4 p. 11-32].

$$R^2 = .97211$$

Standard error of estimate = .988268 kts.

<u>VARIABLE/ TRANSFORM</u>	<u>REGRESSION COEFFICIENT</u>
INTERCEPT	-563.098
I	2.74663
C	94.3518
A	48.7049
C <sup>2</sup>	-4.6753
A <sup>2</sup>	-.6005
C <sup>3</sup>	.077392
AC	-4.49562
A <sup>2</sup> C <sup>2</sup>	.00153818
C <sup>3</sup> A	.00927324
C <sup>3</sup> A <sup>3</sup>	.769943X10 <sup>-5</sup>
I <sup>3</sup> A	.0000905311
IA <sup>2</sup>	.0262874
A <sup>2</sup> I <sup>3</sup>	-.0000161533
A <sup>3</sup> I <sup>3</sup>	.191249X10 <sup>-5</sup>
IC	-.188195
ICA <sup>3</sup>	.0000604516
ICA <sup>2</sup>	-.00373104
C <sup>3</sup> IA <sup>2</sup>	.0000123564
IC <sup>2</sup> A	-.00230188
C <sup>3</sup> IA	.000205707
I <sup>4</sup> C <sup>3</sup> A <sup>3</sup>	.101077X10 <sup>-10</sup>
I <sup>4</sup> CA	-.102061X10 <sup>-6</sup>
C <sup>4</sup> A <sup>3</sup> I <sup>3</sup>	-.233492X10 <sup>-10</sup>
C <sup>4</sup> AI	-.476391X10 <sup>-5</sup>
I <sup>4</sup> C	.440832X10 <sup>-6</sup>
C <sup>4</sup> I	.550886X10 <sup>-5</sup>
C <sup>4</sup> A	-.000212041
AC <sup>2</sup> I <sup>4</sup>	.144642X10 <sup>-8</sup>
A <sup>2</sup> C <sup>4</sup> I <sup>3</sup>	.45315X10 <sup>-10</sup>
A <sup>2</sup> C <sup>4</sup> I	-.285156X10 <sup>-6</sup>
A <sup>4</sup> I <sup>2</sup> C <sup>3</sup>	.81415X10 <sup>-10</sup>
A <sup>4</sup> I <sup>2</sup> C <sup>4</sup>	-.204801X10 <sup>-10</sup>
I <sup>4</sup>	-.782574X10 <sup>-5</sup>
I <sup>4</sup> C <sup>4</sup>	-.487904X10 <sup>-11</sup>
I <sup>3</sup> A <sup>4</sup>	-.107731X10 <sup>-6</sup>
C <sup>4</sup> A <sup>4</sup>	.290421X10 <sup>-9</sup>
C <sup>4</sup> A <sup>3</sup>	-.364546X10 <sup>-6</sup>
C <sup>4</sup> A <sup>2</sup>	-.532767X10 <sup>-7</sup>



Regression equation- For Figure 11-21  
top chart [Ref. 4 p. 11-33].

$R^2 = .99959$

Standard error of estimate = .095246 hrs.

<u>VARIABLE/ TRANSFORM</u>	<u>REGRESSION COEFFICIENT</u>
INTERCEPT	-14.1228
A	-.540052
C	1.18957
A <sup>2</sup> C <sup>4</sup>	-.294347X10 <sup>-7</sup>
AC	.0570829
AC <sup>2</sup>	-.000939808
C <sup>4</sup>	-.70554X10 <sup>-5</sup>

Regression equation- For Figure 11-21  
bottom chart [Ref. 4 p. 11-33].

$R^2 = .99998$

Standard error of estimate = .016675 hrs.

<u>VARIABLE/ TRANSFORM</u>	<u>REGRESSION COEFFICIENT</u>
INTERCEPT	-.00553605
T	1.00062
T <sup>4</sup> I <sup>4</sup>	-.349348X10 <sup>-11</sup>
T <sup>2</sup> I <sup>2</sup>	.153075X10 <sup>-5</sup>
TI	-.00117903
TI <sup>2</sup>	-.216546X10 <sup>-4</sup>
TI <sup>4</sup>	.847453X10 <sup>-8</sup>

2. Flowchart- See Figure B.9.

3. Program listing- See pages 61-63.

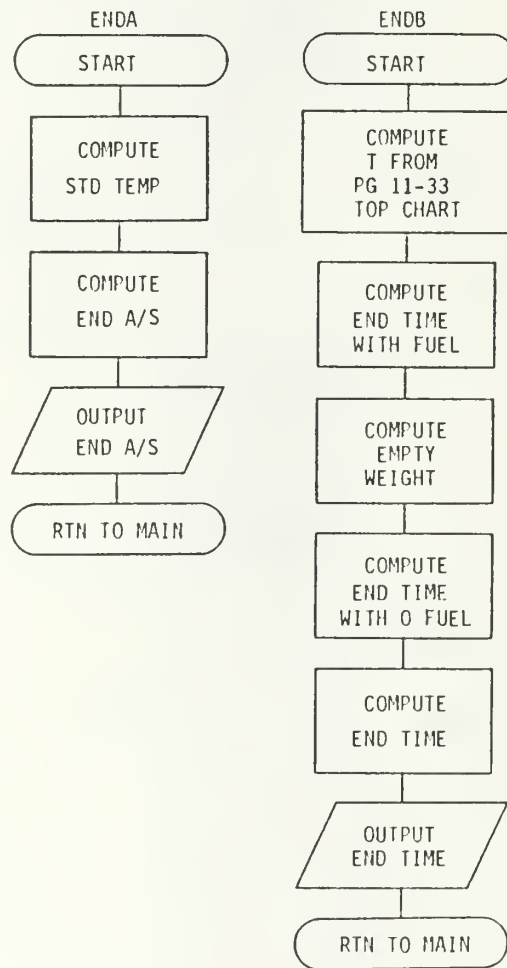


Figure B.9 END Flowcharts

01•LBL "ENDP"  
 02 RCL 04  
 03 15  
 04 -  
 05 RCL 00  
 06 2  
 07 \*  
 08 +  
 09 STO 23  
 10 STO 29  
 11 24.026  
 12 XEQ "QD"  
 13 20  
 14 RCL 23  
 15 X<=Y?  
 16 GTO 05  
 17 4  
 18 RCL 00  
 19 X<=Y?  
 20 GTO 05  
 21 8.001  
 22 X>Y?  
 23 GTO 01  
 24 GTO 02  
 25•LBL 01  
 26 20  
 27 RCL 00  
 28 X<=Y?  
 29 GTO 05  
 30•LBL 02  
 31 "OFF CHART"  
 32 ADV  
 33 RTN  
 34•LBL 05  
 35 -563.098  
 36 RCL 23  
 37 2.74663  
 38 \*  
 39 +  
 40 RCL 00  
 41 94.3518  
 42 \*  
 43 +  
 44 RCL 00  
 45 48.7049  
 46 \*  
 47 +  
 48 RCL 09  
 49 -4.6753  
 50 \*

51 +  
 52 RCL 01  
 53 -.6005  
 54 \*  
 55 +  
 56 RCL 10  
 57 .077392  
 58 \*  
 59 +  
 60 RCL 00  
 61 RCL 00  
 62 \*  
 63 -4.49562  
 64 \*  
 65 +  
 66 RCL 01  
 67 RCL 09  
 68 \*  
 69 .00153818  
 70 \*  
 71 +  
 72 RCL 10  
 73 RCL 00  
 74 \*  
 75 .00927324  
 76 \*  
 77 +  
 78 RCL 10  
 79 RCL 02  
 80 \*  
 81 .769943 E-5  
 82 \*  
 83 +  
 84 RCL 25  
 85 RCL 00  
 86 \*  
 87 .905311 E-4  
 88 \*  
 89 +  
 90 RCL 23  
 91 RCL 01  
 92 \*  
 93 .0262874  
 94 \*  
 95 +  
 96 RCL 01  
 97 RCL 25  
 98 \*  
 99 -.161533 E-4  
 100 \*

101 +  
 102 RCL 02  
 103 RCL 25  
 104 \*  
 105 .191249 E-5  
 106 \*  
 107 +  
 108 RCL 23  
 109 RCL 00  
 110 \*  
 111 -.108195  
 112 \*  
 113 +  
 114 RCL 23  
 115 RCL 00  
 116 \*  
 117 RCL 02  
 118 \*  
 119 .604516 E-4  
 120 \*  
 121 +  
 122 RCL 23  
 123 RCL 00  
 124 \*  
 125 RCL 01  
 126 \*  
 127 -.00373104  
 128 \*  
 129 +  
 130 RCL 10  
 131 RCL 23  
 132 \*  
 133 RCL 01  
 134 \*  
 135 .123564 E-4  
 136 \*  
 137 +  
 138 RCL 23  
 139 RCL 09  
 140 \*  
 141 RCL 00  
 142 \*  
 143 -.00230186  
 144 \*  
 145 +  
 146 RCL 10  
 147 RCL 23  
 148 \*  
 149 RCL 00  
 150 \*

151 .000205707	201 -.000212041	251 -.487904 E-11
152 *	202 *	252 *
153 +	203 +	253 +
154 RCL 26	204 RCL 00	254 RCL 25
155 RCL 10	205 RCL 09	255 RCL 03
156 *	206 *	256 *
157 RCL 02	207 RCL 26	257 -.107731 E-6
158 *	208 *	258 *
159 .101077 E-10	209 .144642 E-8	259 +
160 *	210 *	260 RCL 11
161 +	211 +	261 RCL 03
162 RCL 26	212 RCL 01	262 *
163 RCL 00	213 RCL 11	263 .290421 E-9
164 *	214 *	264 *
165 RCL 00	215 RCL 25	265 +
166 *	216 *	266 RCL 11
167 -.102061 E-6	217 .45315 E-10	267 RCL 02
168 *	218 *	268 *
169 +	219 +	269 -.364546 E-6
170 RCL 11	220 RCL 01	270 *
171 RCL 02	221 RCL 11	271 +
172 *	222 *	272 RCL 11
173 RCL 25	223 RCL 23	273 RCL 01
174 *	224 *	274 *
175 -.233492 E-10	225 -.285156 E-6	275 -.532767 E-7
176 *	226 *	276 *
177 +	227 +	277 +
178 RCL 11	228 RCL 03	278 "END R/S="
179 RCL 00	229 RCL 24	279 ARCL X
180 *	230 *	280 ADV
181 RCL 23	231 RCL 10	281 .END.
182 *	232 *	
183 -.476391 E-5	233 .01415 E-10	
184 *	234 *	
185 +	235 +	
186 RCL 26	236 RCL 03	
187 RCL 00	237 RCL 24	
188 *	238 *	
189 .440032 E-6	239 RCL 11	
190 *	240 *	
191 +	241 -.204801 E-10	
192 RCL 11	242 *	
193 RCL 23	243 +	
194 *	244 RCL 26	
195 .550086 E-5	245 -.702574 E-5	
196 *	246 *	
197 +	247 +	
198 RCL 11	248 RCL 26	
199 RCL 00	249 RCL 11	
200 *	250 *	

```

01*LBL "END0"
02 RCL 29
03 STO 04
04 5.007
05 XEQ "00"
06*LBL 01
07 -14.12228
08 RCL 00
09 -.540052
10 *
11 +
12 RCL 00
13 1.18957
14 *
15 +
16 RCL 01
17 RCL 11
18 *
19 -.294347 E-7
20 *
21 +
22 RCL 00
23 RCL 00
24 *
25 .0570029
26 *
27 +
28 RCL 00
29 RCL 09
30 *
31 -.000939908
32 *
33 +
34 RCL 11
35 -.70554 E-5
36 *
37 +
38 STO 23
39 24.026
40 XEQ "00"
41 -.00553605
42 RCL 23
43 1.00062
44 *
45 +
46 RCL 26
47 RCL 07
48 *
49 -.349348 E-11
50 *

```

```

51 +
52 RCL 24
53 RCL 05
54 *
55 .150075 E-5
56 *
57 +
58 RCL 23
59 RCL 04
60 *
61 -.00117903
62 *
63 +
64 RCL 23
65 RCL 05
66 *
67 -.216546 E-4
68 *
69 +
70 RCL 27
71 RCL 07
72 *
73 .047453 E-8
74 *
75 +
76 FC?C 03
77 GT0 02
78 CHS
79 RCL 27
80 +
81 STO 28
82 INT
83 "END TIME="
84 ARCL X
85 "FHP"
86 FS? 01
87 GT0 04
88 ADV
89 PROMPT
90 GT0 05
91*LBL 04
92 ADV
93 FPA
94*LBL 05
95 RCL 28
96 FRC
97 60
98 *
99 "      +"
100 ARCL X

```

```

101 "FMN"
102 RTN
103*LBL 02
104 STO 27
105 RCL 00
106 RCL 20
107 10
108 /
109 -
110 STO 02
111 9.011
112 XEQ "00"
113 SF 03
114 GT0 01
115 .END.

```

## J. ABILITY TO MAINTAIN FLIGHT WITH ONE ENGINE (SE/EV)

### 1. Equations/Fit statistics-

Regression equation- For Figure 11-23  
top chart [Ref. 4 p. 11-37].

$$R^2 = .99926$$

Standard error of estimate = .50233 % tq.

<u>VARIABLE/ TRANSFORM</u>	<u>REGRESSION COEFFICIENT</u>
INTERCEPT	69.3394
D	3.29399
C <sup>4</sup>	.000125967
C <sup>4</sup> D	-.577415X10 <sup>-4</sup>
C <sup>4</sup> D <sup>2</sup>	-.192526X10 <sup>-5</sup>
C <sup>3</sup> D	.00245945
C <sup>3</sup> D <sup>2</sup>	.424577X10 <sup>-4</sup>
C <sup>2</sup> D <sup>4</sup>	.462872X10 <sup>-6</sup>
CD	-.662361

Regression equation- For Figure 11-23  
bottom chart above  
base line [Ref. 4 p. 11-37].

$$R^2 = .996$$

Standard error of estimate = 1.225218 kts.

<u>VARIABLE/ TRANSFORM</u>	<u>REGRESSION COEFFICIENT</u>
INTERCEPT	449.498
U <sup>-1</sup> H <sup>4</sup>	-.0344426
H <sup>-2</sup>	-31869.1
H <sup>6</sup>	-.295226X10 <sup>-4</sup>
U <sup>7</sup> H <sup>8</sup>	.264768X10 <sup>-13</sup>
U <sup>8</sup> H <sup>8</sup>	-.196344X10 <sup>-14</sup>
U <sup>-7</sup>	46749423
U <sup>-8</sup>	-.349828X10 <sup>9</sup>
U <sup>-5</sup> H <sup>5</sup>	-29.0417
U <sup>-5</sup> H <sup>8</sup>	.0176142
U <sup>-6</sup> H	1120118
H <sup>-5</sup> U <sup>4</sup>	-2663.33
H <sup>-6</sup> U <sup>3</sup>	381481
H <sup>-8</sup> U <sup>4</sup>	-1179202

Regression equation- For Figure 11-23  
bottom chart below  
base line [Ref. 4 p. 11-37].

$R^2 = .99245$

Standard error of estimate = 1.47515 kts.

<u>VARIABLE/ TRANSFORM</u>	<u>REGRESSION COEFFICIENT</u>
INTERCEPT	8824.72
$\exp(U^{-4}H^3)$	61.1876
$\exp(U^{-4}H^4)$	22.1052
$\exp(U^{-3}H^2)$	5.78698
$\exp(U^{-3}H^4)$	$.835267 \times 10^{-12}$
$\exp(U^{-2}H^2)$	-2388.27
$\exp(U^{-2}H^3)$	$-.44832 \times 10^{-8}$
$\exp(U^{-1}H)$	-6109.32
$\exp(U^{-1}H^2)$	$.601748 \times 10^{-6}$
$\exp(H^{-1})$	-210.325
$\exp(2U^{-1}H)$	1954.4

2. Flowchart- See Figure B.10.

3. Program listing- See pages 67-68.



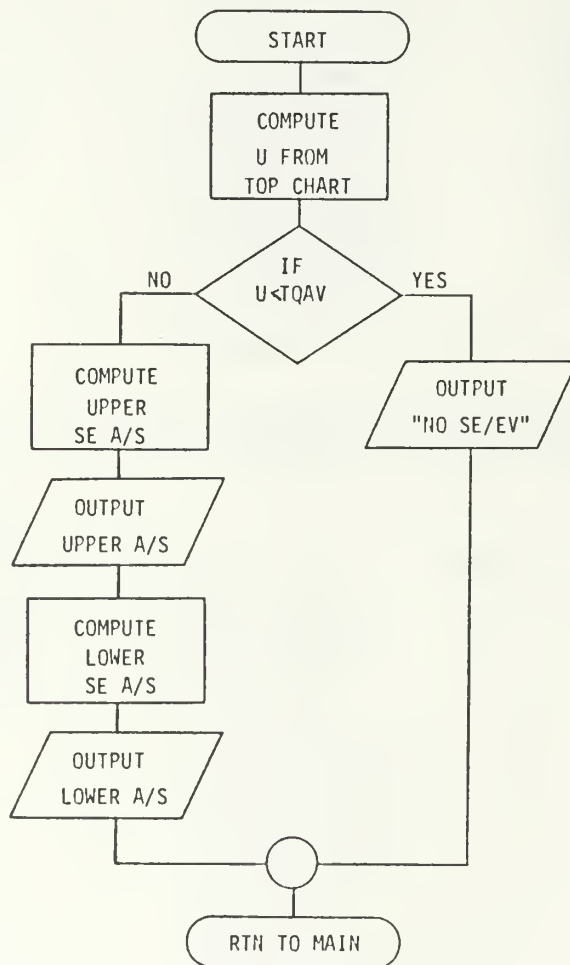


Figure B.10 SE/EV Flowchart

01*LBL "SE/EV"	51 X>Y?	101 *
02 69.3394	52 GTO 01	102 -.196344 E-14
03 RCL 12	53 "NO SE/EV"	103 *
04 3.29399	54 ADV	104 +
05 *	55 RTN	105 RCL 27
06 +	56*LBL 01	106 7
07 RCL 11	57 23.025	107 Y+X
08 .000125967	58 XEQ "QD"	108 46749423
09 *	59 RCL 25	109 *
10 +	60 X12	110 +
11 RCL 11	61 STO 26	111 RCL 27
12 RCL 12	62 RCL 27	112 8
13 *	63 1/X	113 Y+X
14 -.577415 E-4	64 STO 27	114 -.349628 E5
15 *	65 28.030	115 *
16 +	66 XEQ "QD"	116 +
17 RCL 11	67 RCL 30	117 RCL 31
18 RCL 13	68 RCL 27	118 RCL 22
19 *	69 *	119 5
20 -.192526 E-5	70 STO 31	120 Y+Y
21 *	71 449.498	121 *
22 +	72 RCL 27	122 -29.0417
23 RCL 10	73 RCL 25	123 *
24 RCL 12	74 *	124 +
25 *	75 -.034426	125 RCL 31
26 .00245945	76 *	126 RCL 26
27 *	77 +	127 *
28 +	78 RCL 23	128 .0176146
29 RCL 10	79 1/X	129 *
30 RCL 13	80 -31869.1	130 +
31 *	81 *	131 RCL 27
32 .424577 E-4	82 +	132 6
33 *	83 RCL 22	133 Y+X
34 +	84 6	134 RCL 22
35 RCL 09	85 Y+X	135 *
36 RCL 15	86 -.295226 E-4	136 1120118
37 *	87 *	137 *
38 .462872 E-6	88 +	138 +
39 *	89 RCL 27	139 RCL 22
40 +	90 -7	140 -5
41 RCL 08	91 Y+X	141 Y+X
42 RCL 12	92 RCL 26	142 RCL 30
43 *	93 *	143 1/X
44 -.662361	94 .264768 E-13	144 *
45 *	95 *	145 -2663.33
46 +	96 +	146 *
47 10	97 RCL 27	147 +
48 /	98 -8	148 RCL 22
49 STO 27	99 Y+Y	149 -6
50 RCL 22	100 RCL 26	150 Y+X

151 RCL 29	201 E+X
152 1/X	202 .835267 E-12
153 *	203 *
154 381481	204 +
155 *	205 RCL 28
156 +	206 RCL 23
157 RCL 26	207 *
158 1/X	208 E+X
159 RCL 30	209 -2388.27
160 1/X	210 *
161 *	211 +
162 -1179202	212 RCL 28
163 *	213 RCL 24
164 +	214 *
165 "SE A/S="	215 E+X
166 ARCL X	216 -.44832 E-8
167 FS? 01	217 *
168 GT0 04	218 +
169 ADV	219 RCL 27
170 PROMPT	220 RCL 22
171 GT0 05	221 *
172*LBL 04	222 E+X
173 ADV	223 -6109.32
174 PRA	224 *
175*LBL 05	225 +
176 8824.72	226 RCL 27
177 RCL 30	227 RCL 23
178 RCL 24	228 *
179 *	229 E+X
180 E+X	230 .601748 E-6
181 61.1876	231 *
182 *	232 +
183 +	233 RCL 22
184 RCL 30	234 1/X
185 RCL 25	235 E+X
186 *	236 -210.325
187 E+X	237 *
188 22.1052	238 +
189 *	239 RCL 27
190 +	240 RCL 22
191 RCL 29	241 *
192 RCL 23	242 2
193 *	243 *
194 E+X	244 E+X
195 5.78698	245 1954.4
196 *	246 *
197 +	247 +
198 RCL 29	248 " TO "
199 RCL 25	249 ARCL X
200 *	250 .END.

K. INDICATED NEVER EXCEED SPEED (VNE)

1. Equations/Fit statistics-

Regression equation- For Figure 1-138  
chart [Ref. 4 p. 1-173].

$R^2 = .99959$

Standard error of estimate = .483568 kts.

<u>VARIABLE/ TRANSFORM</u>	<u>REGRESSION COEFFICIENT</u>
INTERCEPT	93.7068
D	7.64496
D <sup>4</sup>	-.000541484
C <sup>3</sup> D <sup>3</sup>	.106803X10 <sup>-5</sup>
D <sup>2</sup>	-.168473
C <sup>2</sup> D	-.0383634
C <sup>4</sup> D	.251008X10 <sup>-4</sup>
C <sup>2</sup>	.321101
C <sup>4</sup>	-.000420052

2. Flowchart- See Figure B.11.

3. Program listing- See page 71.

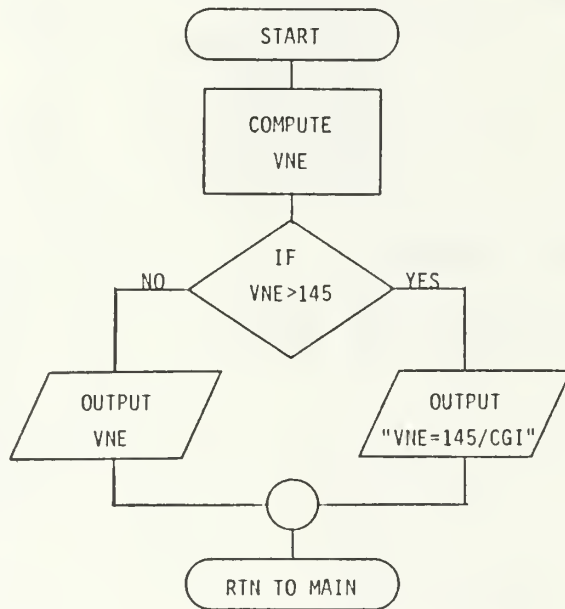


Figure B.11 VNE Flowchart

```

01*LBL "VNE"
02 93.7868
03 RCL 12
04 7.64496
05 *
06 +
07 RCL 15
08 -.000541484
09 *
10 +
11 RCL 10
12 RCL 14
13 *
14 .106803 E-5
15 *
16 +
17 RCL 13
18 -.168473
19 *
20 +
21 RCL 09
22 RCL 12
23 *
24 -.0383634
25 *
26 +
27 RCL 11
28 RCL 12
29 *
30 .251808 E-4
31 *
32 +
33 RCL 09
34 .321101
35 *
36 +
37 RCL 11
38 -.000420052
39 *
40 +
41 145
42 X<=Y?
43 GTO 01
44 "VNE="
45 ARCL Y
46 ADV
47 RTH
48*LBL 01
49 "VNE=145/CGI"
50 ADV
51 .END.

```

## LIST OF REFERENCES

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